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COST OF TERMINATING CONTRACTS STUDY (COTCOS-II).(U)
APR 77 J S SUTTERFIELD

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TR-77-25

# COST OF TERMINATING CONTRACTS STUDY (COTCOS-II)

J. S. Sutterfield

April 1977

Final Report





U.S. ARMY AVIATION SYSTEMS COMMAND
Systems Analysis Office
Developmental Systems Analysis Division
P.O. Box 209
St. Louis, Missouri 63166

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## REPORT DOCUMENTATION PAGE

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| | |
|---|---|
| 1. REPORT NUMBER: USAAVSCOM TR 77-25 | 2. GOVT ACCESSION NO. |
| 3. RECIPIENT'S CATALOG NUMBER | |
| 4. TITLE (and Subtitle): Cost of Terminating Contracts Study (COTCOS-II). | 5. TYPE OF REPORT & PERIOD COVERED: Final Report. |
| 6. PERFORMING ORG. REPORT NUMBER: DRSAV-D-77-7 | |
| 7. AUTHOR(s): J. S. Sutterfield | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Aviation Systems Command, Systems Analysis Office, Developmental Systems Analysis Division (DRSAV-DD), P.O. Box 209, St. Louis, Mo 63166 | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Aviation Systems Command, Systems Analysis Office (DRSAV-D), PO Box 209, St. Louis MO. 63166 | 12. REPORT DATE: April 1977 |
| | 13. NUMBER OF PAGES: 40 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 46p. | 15. SECURITY CLASS. (of this report): UNCLASSIFIED |
| | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for Public Release; Distribution Unlimited

18. SUPPLEMENTARY NOTES

This report requested and prepared in cooperation with the Directorate for International Logistics. Study results and recommendations approved by requestor.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Termination Liability
Curve Fit
Regression Curve
Correlation
Statistics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study had as its object the development of a curve of termination liability for use on Army shop set contracts. An "equally likely" or average curve was graphically developed from eight sets of contract data. From this graphical curve an equation was developed. This equation provided an analytical curve that almost perfectly reproduced the original graphical curve.

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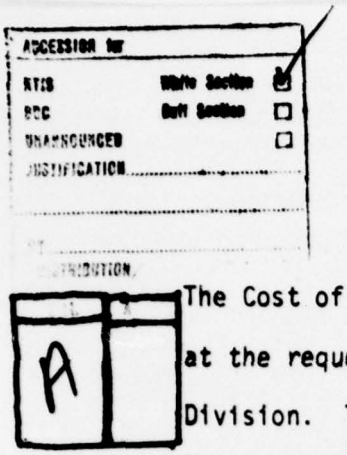


## EXECUTIVE SUMMARY

The Cost of Terminating Contracts Study II (COTCOS-II) was initiated at the request of the Directorate for International Logistics, Programs Division. The request was made as a result of concern as to whether the progress payments being made by foreign military purchases of shop-sets for Army aircraft were adequate to defray the cost of contract termination, i.e., defray the termination liability.

A set of termination liability tables had been developed by the Air Force and were being recommended for use throughout the DOD complex. There was doubt, however, regarding the adequacy of these tables for foreign military transactions involving shop sets for Army aircraft. Thus, the objectives of the study were:

1. Determining whether DARCOM information would have been adequate for several representative shop-set contracts.

2. In the event DARCOM information was found to be inadequate, developing a curve that would provide adequate progress payments in 50 percent of the cases, i.e., an "equally likely" curve.

The assumptions forming the basis for the study were as follows:

1. The total shop-set costs follow the same curve as the one developed for shelters.

2. That the reporting of cumulative costs "lags" the actual incurrence of costs; this reporting lag is assumed to increase linearly until it reaches 60 days midway through the contract and to remain constant thereafter for the remaining half of the contract.

3. That a "normal" contract is closed out 90 days after the last delivery is made.

4. That cost incurred in a continuous function, when in reality it is discrete and discontinuous.

5. That the small number of contracts available for analysis is sufficient to provide a basis for sound generalizations about future cases.

The following conditions constrained the study:

1. A relatively small number of "clean contracts" on which to perform the analysis.

2. Lack of uniformity in the incurrence and reporting of costs.

The study resulted in the average of "equally likely" cost incurred curve shown in Figure 13, page 29 and the equation for the curve shown on page 39. The curve for shop-sets was found to be very similar to that previously developed for airframes, the maximum divergence between the two being only 8.73 percent and occurring at 45.82 percent of contract completion.

The conclusions from the study were that:

1. The AVSCOM average or "equally likely" curve of cost incurred for shop sets fulfills the current DARCOM definition for a termination liability curve.

2. The small difference between the aircraft and shop-set curves makes it more desirable at present to use the aircraft curve for shop-sets than to have two separate curves.

3. A greater number of cases must be analyzed in order to render the analysis more statistically sound.

The foregoing conclusions gave rise to the following recommendations:

1. That the AVSCOM average or "equally likely" curve for aircraft be adopted for the present as the basis for reckoning the payments to be made by FMS customers who purchase shop-sets.

2. That a computer system be developed for using future contractual reporting information to determine whether the use of different curves for shop-sets and aircraft will ever be necessary.

## ACKNOWLEDGMENTS

The author wishes to thank the following personnel from the Directorate for International Logistics for the assistance rendered on this study.

Mr. John Maddaleno

Mr. John Galen

Mrs. Mary Ann Trittschuh

Mrs. Agnes Fogg

Special thanks are due Mrs. Marcella Isom, who gave a considerable amount of her time to the collection of data for this study, as well as helping with computations in a related task that was previously levied by the Directorate for International Logistics.

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## INTRODUCTION

Prior to 1973 the volume of foreign military sales in which USAAVSCOM was involved was relatively small; the combined volume for FY 71 and FY 72 was less than $100M. However, in FY 73 there was a sharp increase in the volume of foreign military sales (FMS); the volume for FY 73 was more than five times the combined volume for FY 71 and FY 72. In anticipation of a continuing large volume of foreign military sales, the Directorate for International Logistics was established.

Each FMS Case requires a schedule of payments to be made by the customer. These payments are used to defray a percentage of those costs that were estimated as going to be incurred during the 90 days following receipt of the payment. Prior to FY 73, when the dollar volume of foreign military sales was relatively small, there was little concern as to whether or not the schedule of payments was representative of the incurred costs. But with the increasing dollar volume of foreign military sales, there has been an attendant increase in concern about the adequacy of the payments to defray the incurred costs of a contract should it be terminated.

This schedule of payments, called termination liability payments, is constructed by supposing that the contractor's incurred costs will follow a certain profile. The amount of each payment is normally the sum of the cost estimated to be incurred 90 days after payment and the estimated amount that would be required to "clean-up" the contract if it were terminated.

However, in a recent letter from the DARCOM Plans, Systems and Analysis Office, page 2 of Incl 1, termination liability was defined to be just the costs estimated to be incurred by the contractor 90 days hence; no allowance is to be included for possible "clean-up" charges. Incl 2 of the above letter contained a table of termination liability figures. DARCOM MSCs were directed to use this table of values in computing termination liability in all sales agreements undertaken subsequent to 1 August 1976.

Prior to beginning this study Systems Analysis Office had completed a similar study for Army aircraft FMS cases. The objectives of that study were the same as those of this study. Namely:

1. Determining whether DARCOM information would have been adequate for several representative aircraft shop-set contracts.

2. In the event DARCOM information was found to be inadequate, developing a curve that would provide adequate progress payments in 50 percent of the cases, i.e., an "equally likely" curve.

## ASSUMPTIONS

The COTCOS II analysis was based upon the following assumptions:

1. That total shop-set costs follow the same curve as that developed for shelters.

2. That the reporting of cumulative costs "lags" the actual incurrence of costs; this reporting lag is assumed to increase linearly until it reaches 60 days midway through the contract and to remain constant thereafter for the remaining half of the contract.

3. That a "normal" contract is closed out 90 days after the last delivery is made.

4. That cost incurred is a continuous function, when in reality it is discrete and discontinuous.

5. That the small number of contracts available for analysis is sufficient to provide a basis for sound generalizations about future cases.

## CONSTRAINTS

The COTCOS II analysis was constrained by the following considerations:

1. A relatively small number of contracts on which to perform the analysis.

2. Lack of uniformity in the incurrence and reporting of costs.

## METHODOLOGY

The methodology for COTCOS consisted first of the manual extraction of cumulative cost incurred values with the corresponding date through which each cost had been accumulated. These costs, with their respective dates, were obtained from the DD 1195 forms for each contract, the standard form for requesting progress payments.

Next, the data were normalized. This was accomplished by dividing each value of cost incurred by the total contract price. Assumption number one underlay this calculation. This assumption is warranted because the shelter cost comprises 85 to 90 percent of the total shop-set cost. Also, the assumption is warranted because it never results in a deficiency of funds, as can be shown. Next, the elapsed time for each incurred cost was divided by the total contract time. The contract time was considered to begin when the contract was signed, and to end 90 days after the last delivery was made. In order to account for the time lag between the incurrence of a cost and its reporting, the reported elapsed time values were adjusted based upon assumption number two. It is in the computation of the end point of the contract that assumption number three comes to bear. Now, with each value of cost incurred expressed as a percent of total contract cost and each corresponding date of accumulation expressed as a percent of contract completion, the points were plotted with percent contract completion on the abscissa and percent total contract cost on the ordinate.

After the data had been plotted, a continuous curve was sketched through the points. The curve represented a manual approximation to a curve of best fit. Assumption number four enters at this point, for the data do not comprise a continuous function, but rather a discrete function.

No attempt was made to correlate the delivery schedules with their respective curves of cost incurred, because in almost all cases it was not possible to obtain delivery schedules, and it was difficult to obtain even dates of final delivery.

When each of the eight data sets had been plotted, and a curve had been sketched through each data set, it was then desired to obtain a sort of average, or "equally likely," curve of cost incurred; that is, a curve for which the cost incurred up to any given percent of contract completion time would be equal to or greater than the cost incurred in 50 percent of the contracts during the same percent of contract completion time. In order to construct this "equally likely" curve it was necessary to make assumption number five. Next, the ordinates for the eight curves were averaged at 10 percent intervals through a percent contract completion of 100 percent. Then a continuous curve was drawn, connecting the eleven average points.

The next step was to determine whether an analytical expression might be obtained that would provide a good approximation to the "equally likely" curve.

It was determined that a function of the form

$$Y = A\left[1-e^{-BX^2}\right]$$

provides a very satisfactory approximation to the manually constructed "equally likely" curve, just as was the case with the aircraft curve. From the conditions of the problem that the above function must satisfy, it was possible to solve for the constants "A" and "B" such that the final function provided an almost perfect reproduction of the manually constructed "equally likely" curve. A discussion of the fitting of the above function to the manual curve can be found in Appendix C.

The last part of the methodology had to do with the development and programming of a scheme for determining the correlation between the "equally likely" curve and the original data. This was done using standard correlation equations and programming techniques.

So far as the DARCOM data were concerned, they came with normalized (percentage) values for contract cost. Also, it was discovered that by normalizing the DARCOM data for a given length contract that it was possible to plot all sets of data on the same curve. The normalization of the contract time values was accomplished as described above.

## RESULTS AND DISCUSSION

Figures 1 through 8, pages 17 through 24 show in graphical form the results of the analysis of the eight contracts. For the purpose of comparison, the eight AVSCOM curves are shown with the DOD termination liability curves in Figure 9, page 25. It will be seen that the contract having the greatest percent of total contract cost for any given percent of contract completion was Composite Technology contract number 1098 for the Couse type shelter. At the other extreme Brunswick Corporation contract number 9213 for the MUST shelter had the least percent of total contract cost for any given percent of contract completion. Container Research Corporation contract number 0605 was second high through the first 16.5 percent of contract completion, crossing Composite Technology contract number 0869 at the 16.5 percent point and remaining third high thereafter. Contract number 0869 becomes and remains second after the 16.5 percent point. Missouri Research Laboratories contract number 0987 is fifth from the top through the first 18 percent of contract completion, but at this point it overtakes Missouri Reasearch Laboratories contract number 8162 and moves into fourth place. Number 0987 remains in fourth place through 50.5 percent of contract completion at which point it is overtaken by Brunswick Corporation contract number 9206; this contract remains in fourth place from the 50.5 percent point on. Contract numbers 8162 and 0855 proved to be very interesting cases. While number 0855 had only five points, including the end points, it nevertheless appears that the curve of best fit through these points is

the DOD curve. Hence, these two curves are shown as identical in Figure 9. The curve for number 8162 is a little above the curve for number 0855 (and DOD curve ) to about 55 percent of contract completion. At this point the two curves become identical. The two curves have a maximum difference of only about 4.6 percent, this difference occurring at a contract completion value of about 28 percent. After a contract completion value of about 42 percent, the two curves have next to the least values of percent of contract cost for any given percent of contract completion, curve 9213 from a Brunswick corporation contract being the only one lower than these two. It is interesting that both 0855 and 8162 are from contracts with Missouri Research Laboratories.

It does not appear that any correlation is possible between the dollar value of contracts and the rate at which they increase in percentage of contract cost. For Composite Technology contract numbers 1098 and 0869, the dollar value of 1098 is less than that of 0869. Yet, number 1098 increases more rapidly than 0869. The same things will be found to be respectively true for Brunswick Corporation contract numbers 9206 and 9213. Thus, on the basis of these two pairs of contracts, one might be tempted to generalize and say that the less the dollar value of a contract for a given contract, the more rapid the increase in percentage of total contract cost. However, if one attempted to apply this rule to the three contracts of Missouri Research Laboratories, numbers 0987, 8162 and 0855, he would find the generalization to be invalid.

Neither does it appear that any correlation is possible between the length of a contract and the increase in the percent of total contract cost. Again for Composite Technology Contract numbers 1098 and 0869, the length of 1098 is less than that of 0869. Yet number 1098 increases more rapidly in percent of contract cost than does 0869. The same things will be found to be respectively true for Brunswick Corporation Contract numbers 9206 and 9213. Thus, one might again be tempted to generalize and say that the less the length of a contract, for a given contract price the more rapid the increase in the percent of total contract cost. Once again, however, the generalization will be found to be violated by the Missouri Research Laboratories contracts. It doesn't appear, either, that any relationship exists between the increase in percent of contract cost and the ratio of contract cost to contract length or the inverse ratio, contract length to contract cost. Thus, based upon the available information, it does not appear possible to make any generalizations about the contracts as grouped according to manufacturer, and certainly none can be made about the whole group of contracts. It may be that a relationship exists between the increase in the percent of contract cost and the time until first delivery, but not enough information is available on first delivery dates to permit a test of this hypothesis.

Figure 10, page 26 shows a comparison between the DOD curve and the graphical average or "equally likely" curve for shop sets. As was the case with the "equally likely" curve for aircraft, the "equally likely" curve for shop-sets lies above the DOD curve; although not so far above the DOD curves as the aircraft curve lies.

Figure 11, page 27 presents a comparison between the graphical "equally likely" curves and its analytical "equally likely" approximation. The analytical approximation is excellent, yielding a correlation coefficient of 0.97 with a standard error of 1.06. Thus, the analytical curve is within $\pm$ 1.06 percent of the graphical curve about 68 percent of the time and is only about 2.5 percent lower than the graphical curve at the point of maximum divergence, at which is about 74 percent of contract completion.

Figure 12, page 28 shows the analytical curve plotted along with the eight sets of contract data. The correlation coefficient between the curve and data is almost identical with that for the aircraft curve and data (Reference 1, Figure 9, page 26.) However, the dispersion of the shelter data about this curve is considerably greater than was the dispersion of the aircraft data about the curve developed from them. This means that the aircraft curve has a higher confidence level than the shop-set curve. Figure 13, page 29 presents a comparison of the "equally likely" shop-set curve and the "equally likely" aircraft and DOD curves. The shop-set curve is everywhere greater than the DOD curve, the maximum difference being about 15.5 percent and occurring at approximately 45 percent of contract completion. Relative to the aircraft curve, the shop-set curve is everywhere lower. The maximum difference between these two curves has been calculated to be 8.73 percent at a percent contract completion value of about 46 percent.

## CONCLUSIONS

From a comparison of the curves shown in Figure 9, it is evident that the DOD termination liability schedule would not provide an adequate payment schedule for Army aircraft contracts. Thus, a different payment schedule is required for Army aircraft shop set contracts than the one recommended by DOD in Reference 3.

Now, according to page 2 of Reference 3, termination liability is defined as the sum of the disbursements, the cash holdback and the incurred costs. This amounts to defining termination liability as being the sum of all of the contractor's incurred costs. This being the case, the AVSCOM average incurred cost curve for shop-sets fulfills the DOD definition for a termination liability curve and can be considered an "equally likely" termination liability curve for Army shop-set contracts.

The curve obtained for shop-sets has the same mathematical form as the curve developed for aircraft. There are slight but insignificant differences between the respective constants in the two equations, and these differences account for the fact that the aircraft curve is always a little higher than the shop-set curve. Now, shop-set cases are of relatively low dollar value, so that it would be possible to use the aircraft curve for shop-set cases without charging a customer excessively. It would also be possible to use the shop-set curve for aircraft cases without incurring too great a deficiency, if any, in funds. Since the two

curves are so similar, it would be preferable to use one curve for both types of cases rather than to propagate "another monster." If future cases should modify either curve substantially, it would always be possible to begin using the second curve.

The results of this study, in order to have greater applicability to future cases, should be modified as required by the results of future contracts. In order to do this, it will be necessary to analyze future cases as they become available for analysis. Such analysis might reveal whether or not a relationship exists between the rate at which the normalized cost grows, and one of the other contract variables (See pages 9 and 10 of this report).

## RECOMMENDATIONS

Based upon the foregoing conclusions the following recommendations are made:

1. That the AVSCOM average or "equally likely" curve for Army aircraft, Figure 13, be adopted as the basis for reckoning the payments to be made by FMS customers who purchase shop-sets for Army type aircraft. Because of this recommendation no point for point comparison has been made between values from the "equally likely" shop-set curve and values from the DOD curve. Instead a comparison has been made between values from the "equally likely" aircraft curve and values from the DOD curve. This comparison is shown in Table I, pages 31 through 34.

2. That a computer system be developed for using future contractual reporting information to modify the AVSCOM shop-set curve as may be required to make it more descriptive.

## REFERENCES


1. USAAVSCOM TR 76-44, Nov. 76, Title: "Cost of Terminating Contracts Study (COTCOS-I)

2. USAATAC Systems Analysis Office Report No. 76-039, July 1976, subject: "Termination Liability Study for FMS Cases."

3. DACA-FAL-L Message, 30 Jul 76, subject: "Costs Included in Payment Schedules for Dependable Undertaking FMS Cases."

4. DRSIL-WS Letter, 22 Jul 76, subject: "Costs Included in Payment Schedules on Dependable Undertaking FMS Cases."

5. DAF Letter, 12 Jul 76, subject: "FMS C-130 Expenditures Forecast."

6. USAILCOM Letter, 12 Mar 76, Subject: "Financial Arrangement for FMS Dependable Undertaking Cases."

7. USAILCOM Letter, 12 Feb 76, subject: "Financial Arrangement for FMS Dependable Undertaking Cases."

# APPENDEX A - FIGURES

FIGURE 1-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
CONTRACT NO. 9206, BRUNSWICK CORP., MUST SHELTER

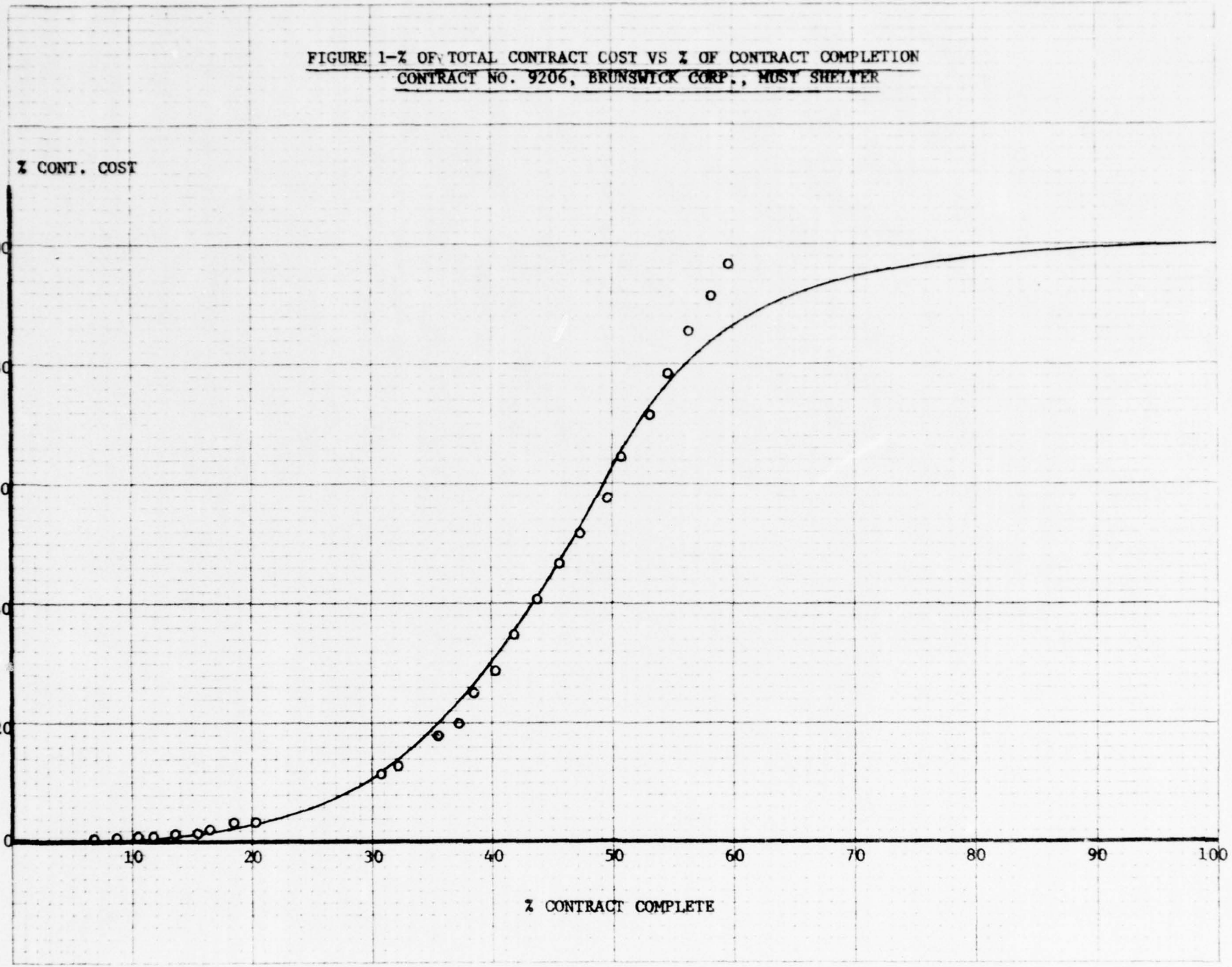


FIGURE 2-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
CONTRACT NO. 9213, BRUNSWICK CORP., MUST SHELTER

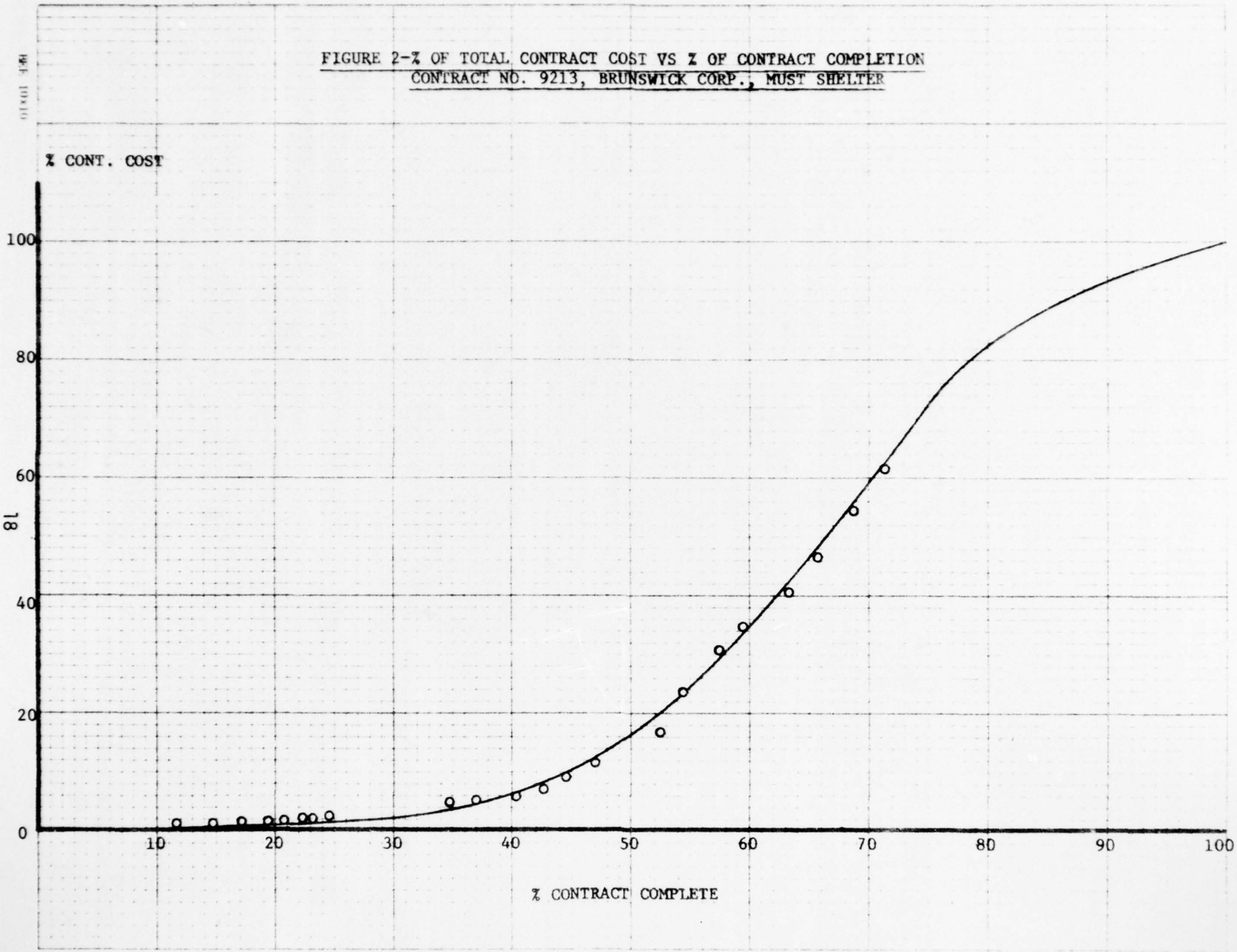


FIGURE 3-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
CONTRACT NO. 0605, CONTAINER RESEARCH CORP., COUSE SHELTER

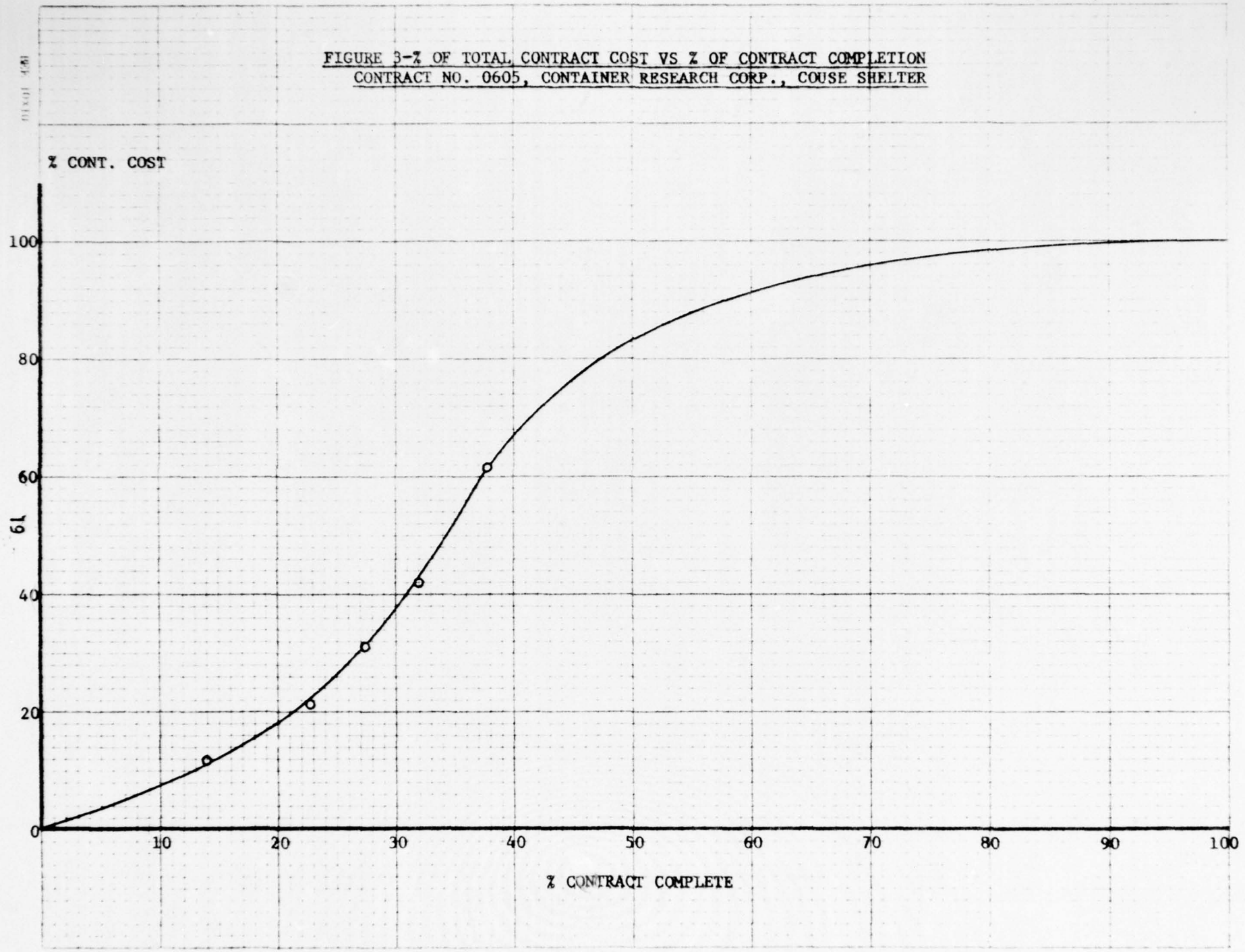
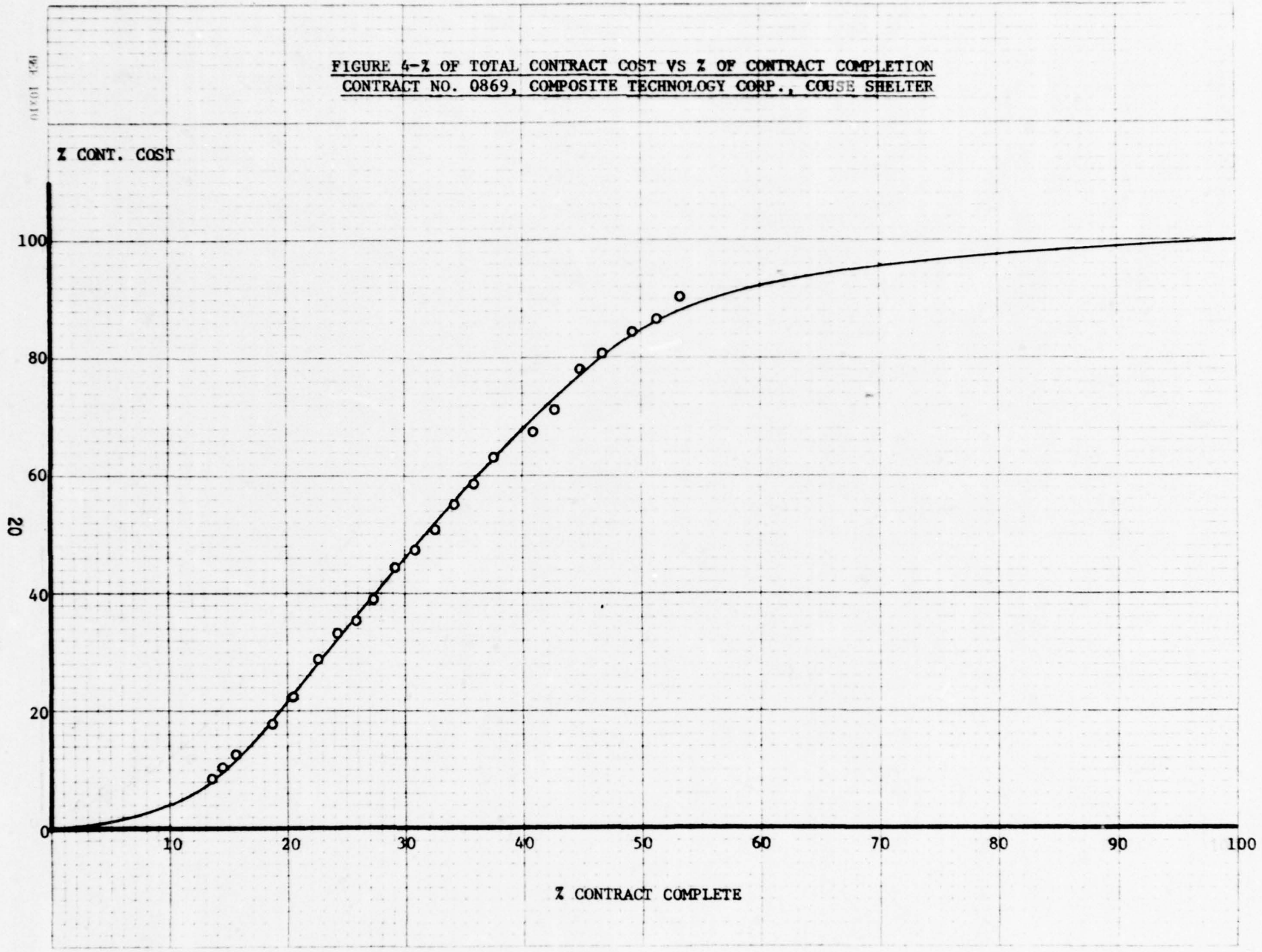


FIGURE 4-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
CONTRACT NO. 0869, COMPOSITE TECHNOLOGY CORP., COUSE SHELTER



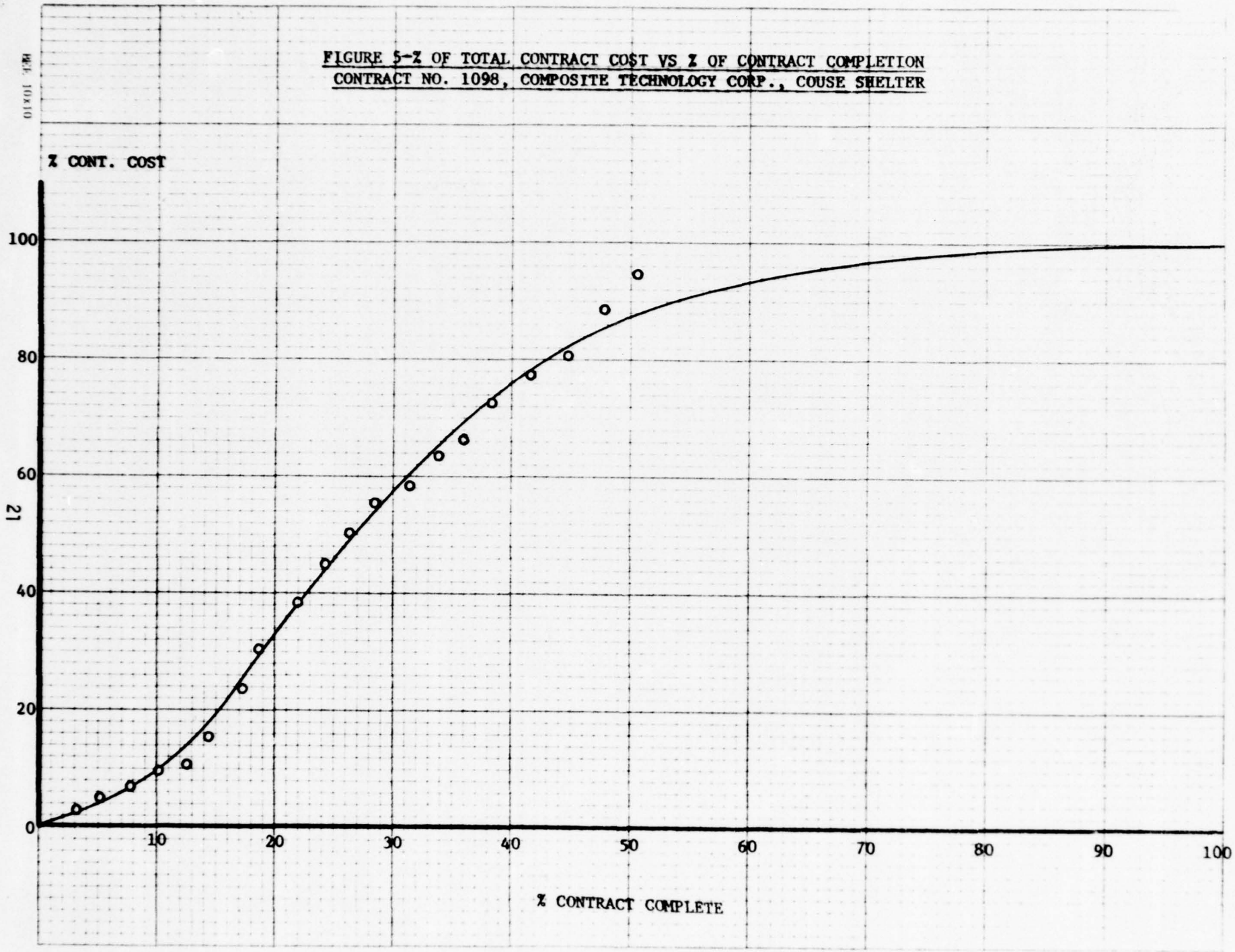


FIGURE 5-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
CONTRACT NO. 1098, COMPOSITE TECHNOLOGY CORP., COUSE SHELTER
% CONT. COST
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
100
% CONTRACT COMPLETE

FIGURE 6-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
CONTRACT NO. 0855, MISSOURI RESEARCH LABS, COUSE SHELTER

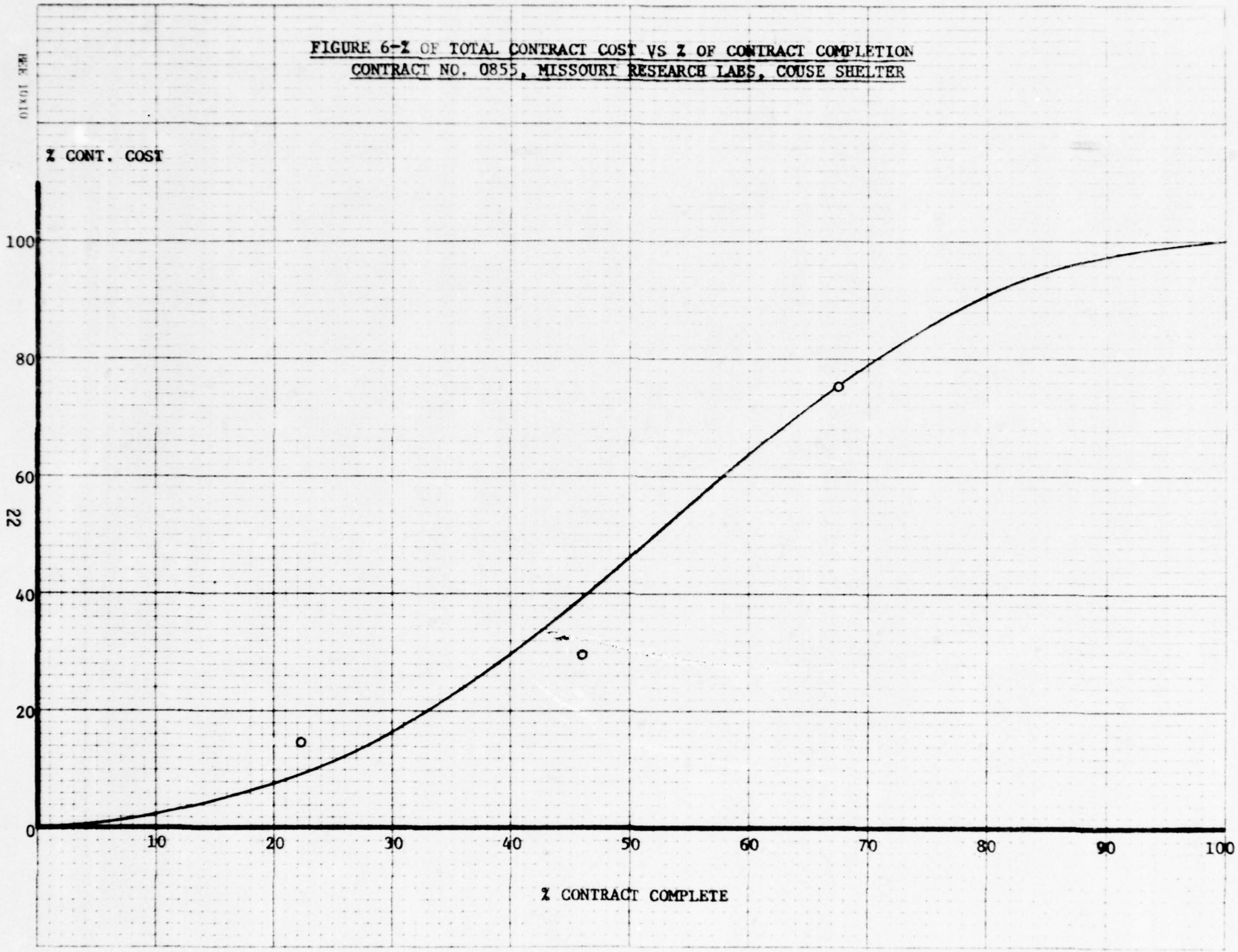


FIGURE 7-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
CONTRACT NO. 0987, MISSOURI RESEARCH LABS, COUSE SHELTER

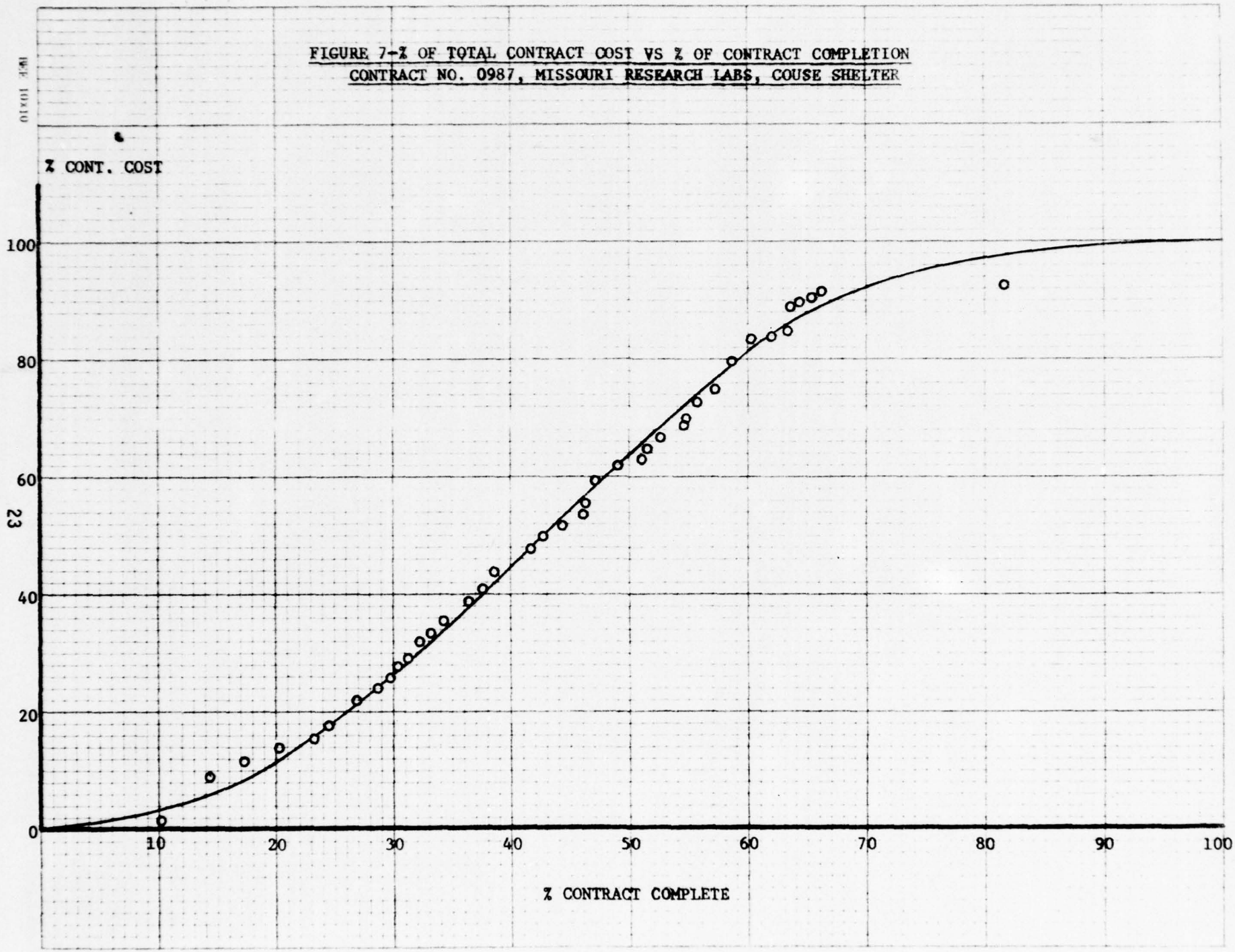


FIGURE 8-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION

CONTRACT NO. 8162, MISSOURI RESEARCH LABS, COUSE SHELTER

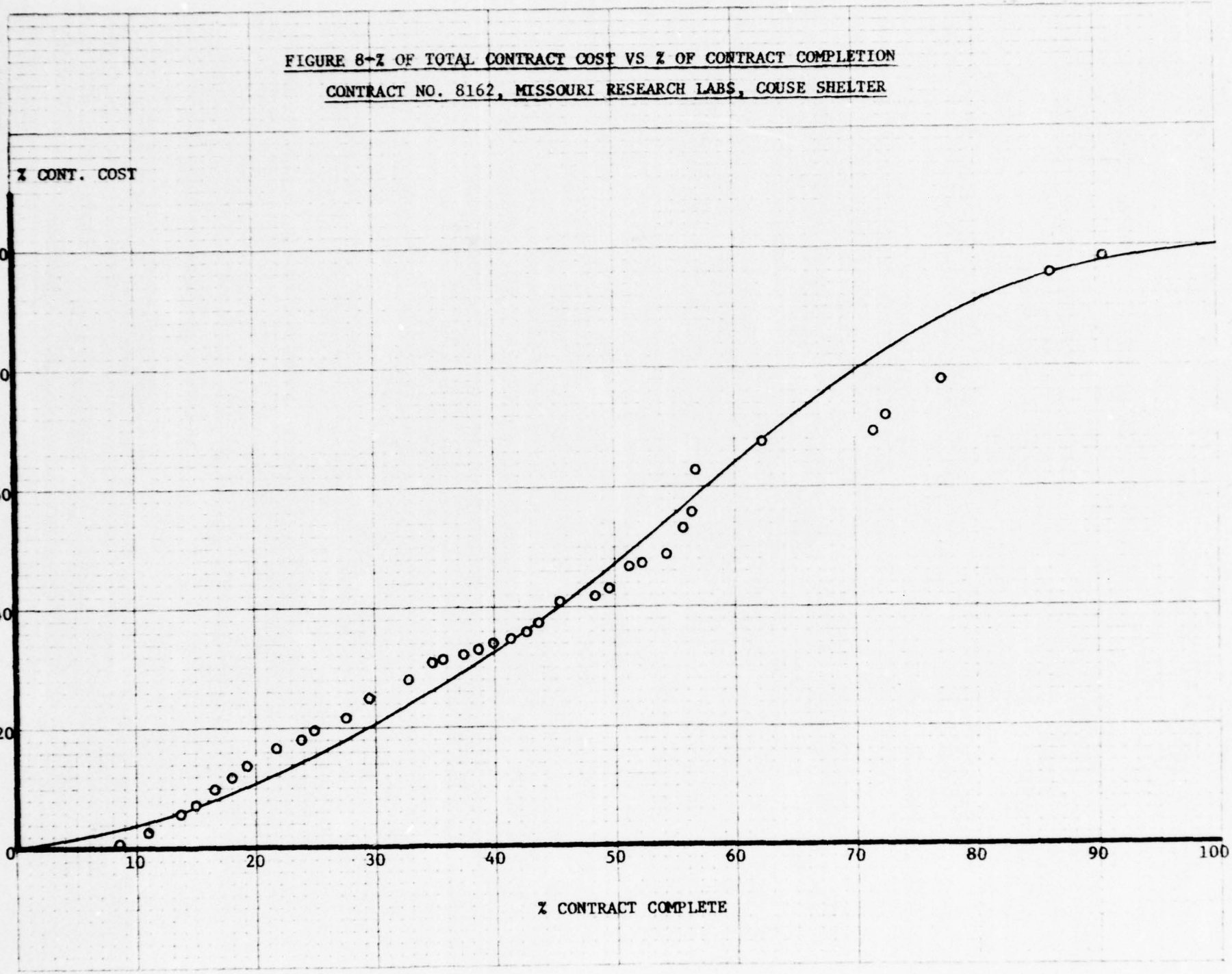


FIGURE 9-% OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
COMPARISON OF CONTRACT CURVES AND DOD CURVE

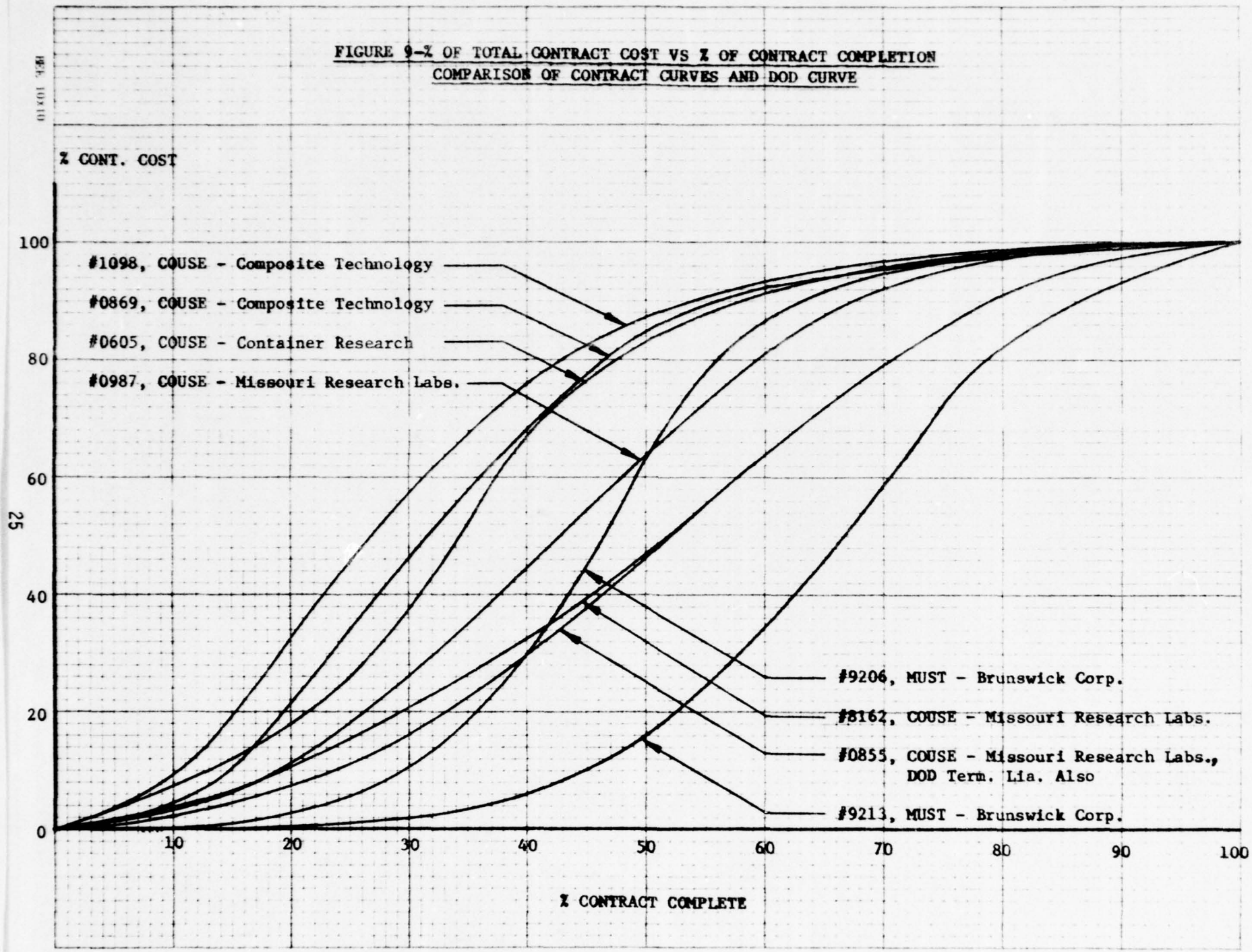


FIGURE 10 - % OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION FOR SHOP SETS
COMPARISON BETWEEN GRAPHICAL EQUALLY LIKELY AND DOD CURVES

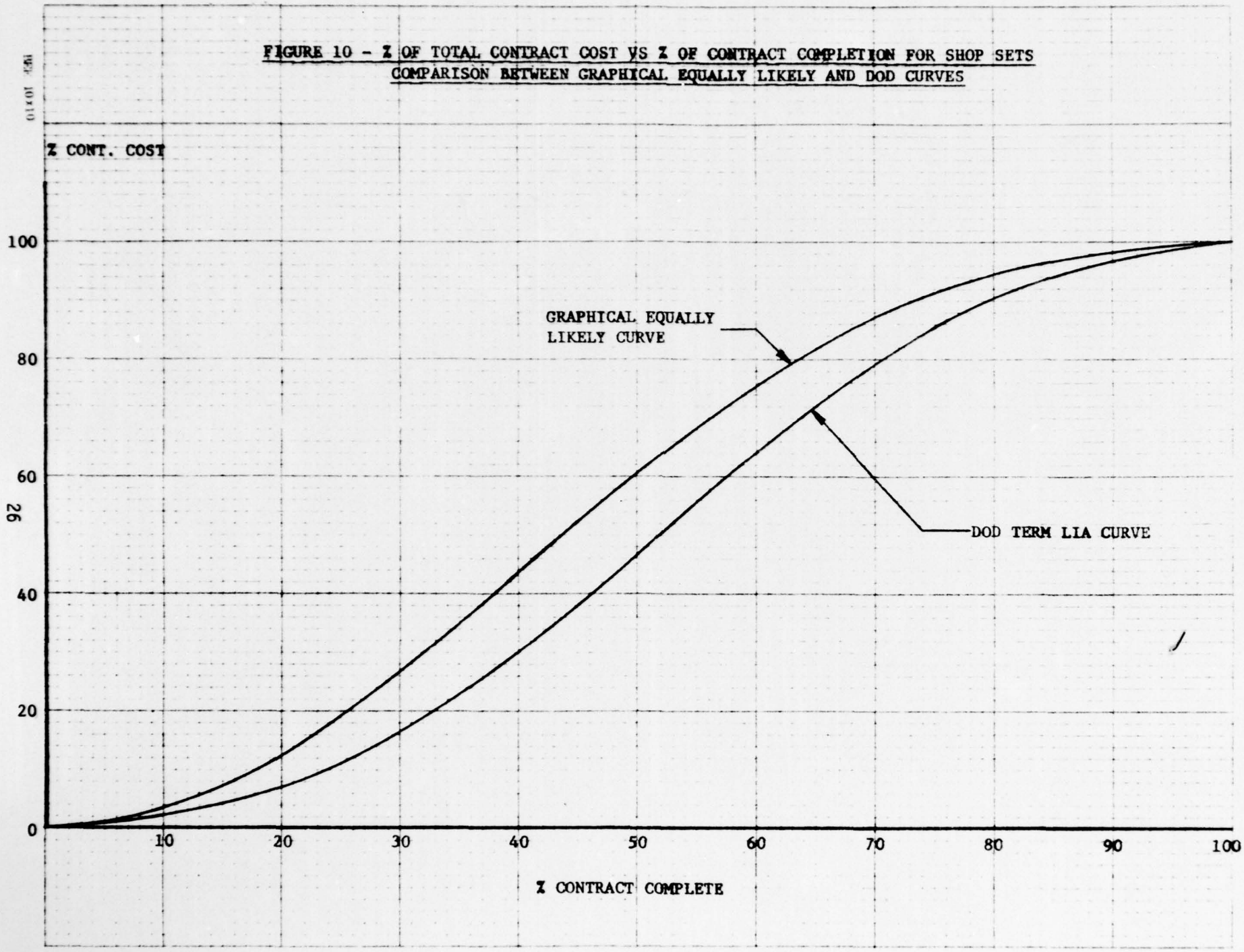


FIGURE 11- % OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION FOR SHOP-SETS
COMPARISON BETWEEN ANALYTICAL AND GRAPHICAL EQUALLY LIKELY CURVES

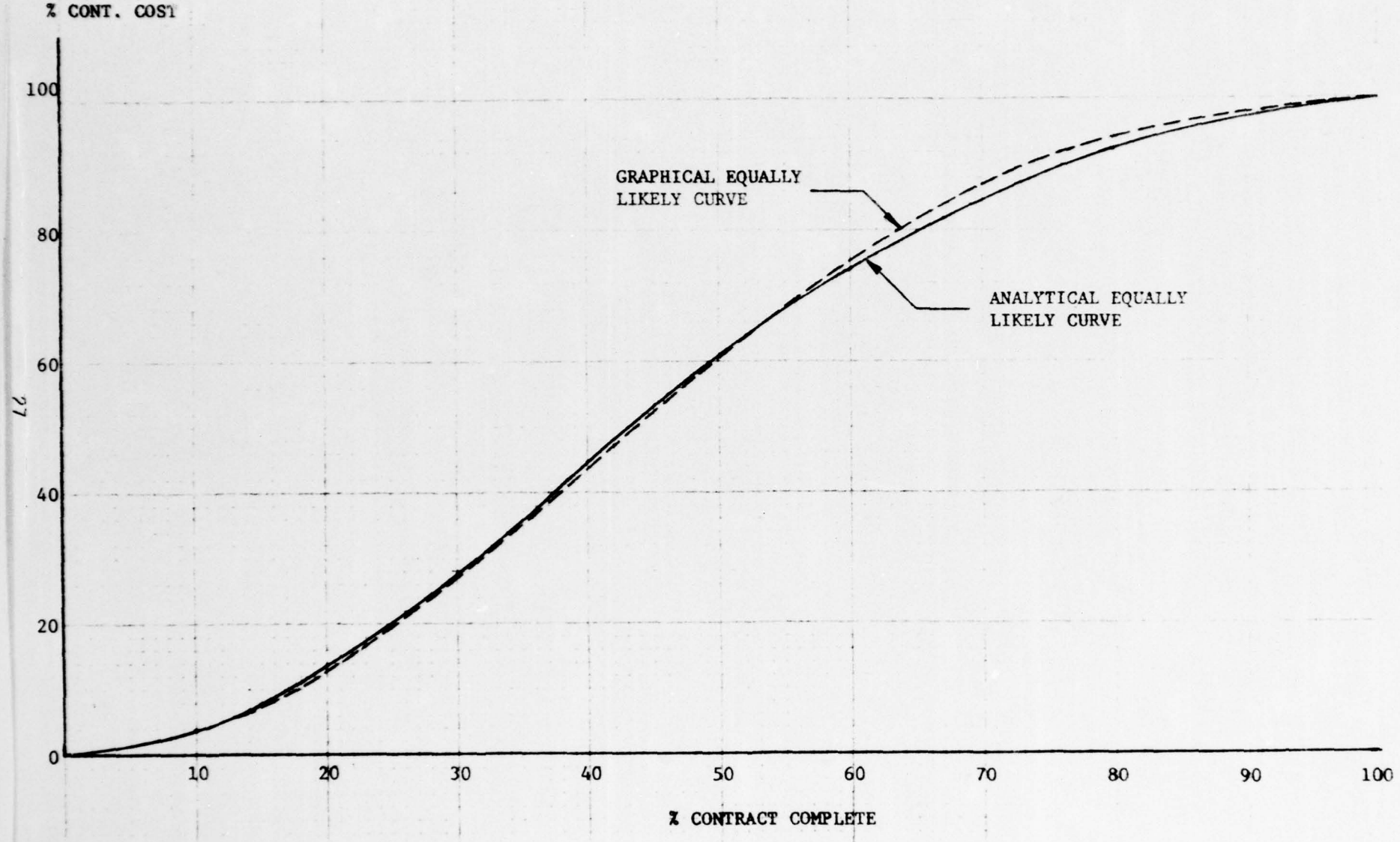


FIGURE 12 - % OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION
FIT OF ANALYTICAL CURVE TO THE EIGHT SETS OF CONTRACT DATA

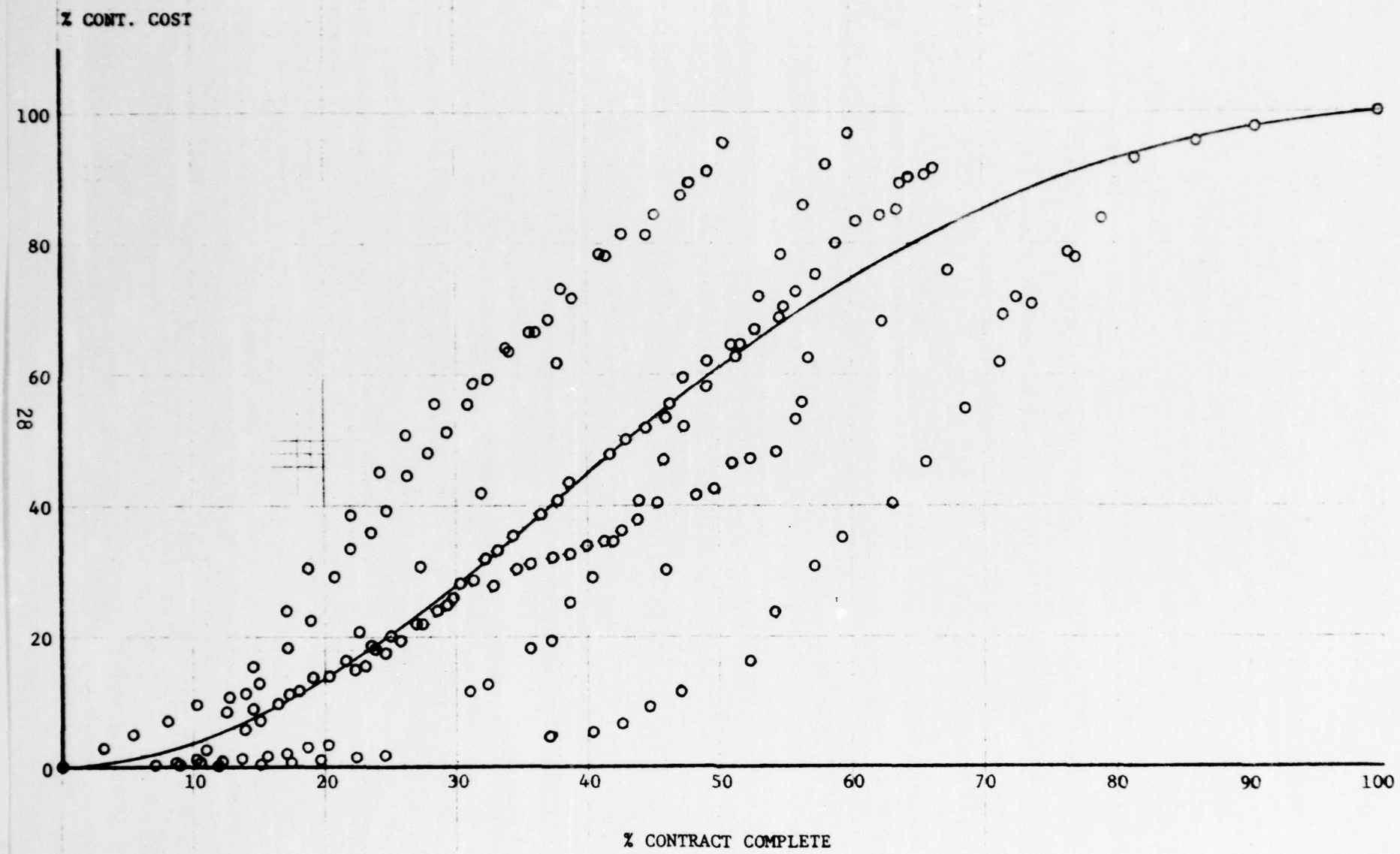
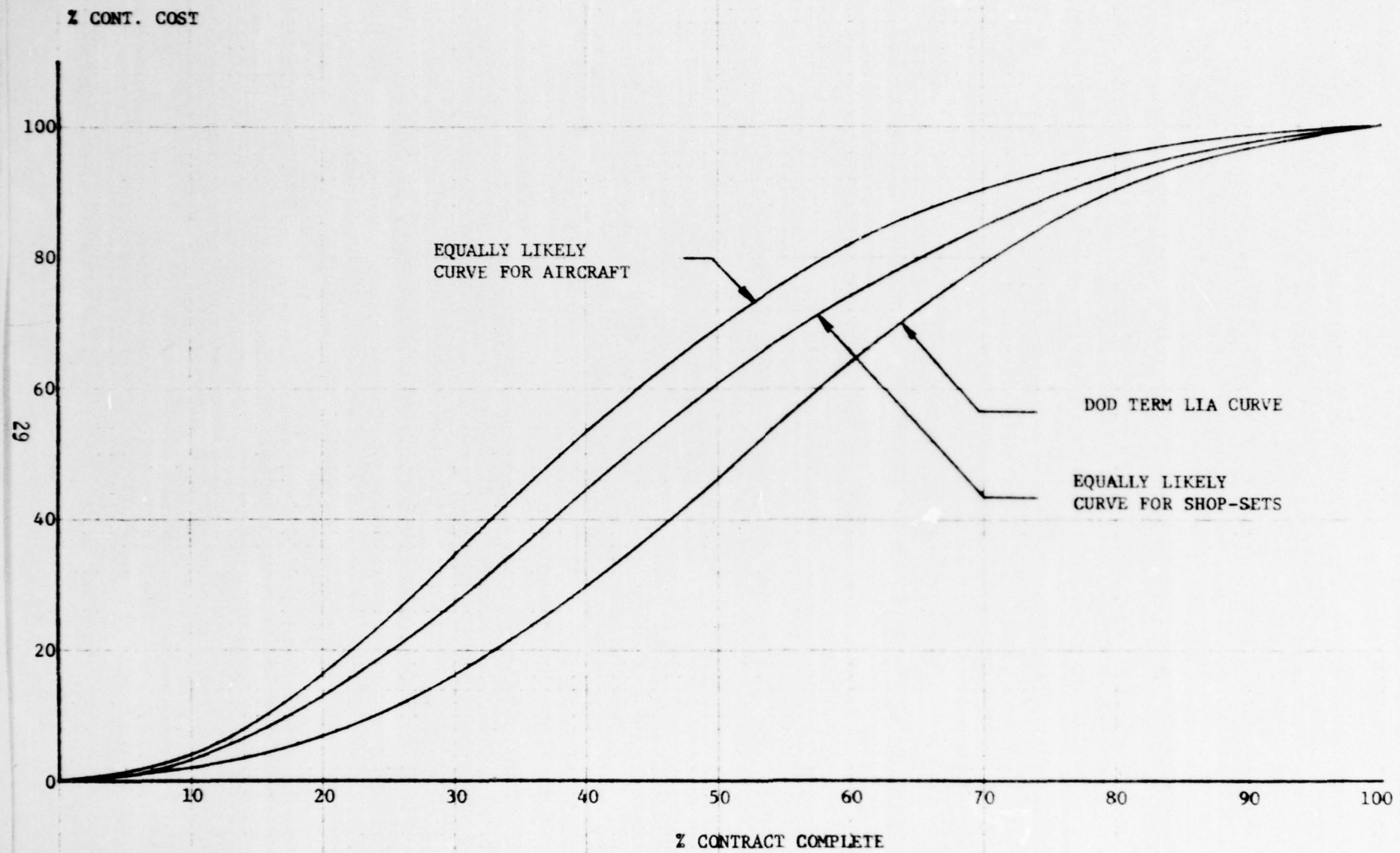


FIGURE 13 - % OF TOTAL CONTRACT COST VS % OF CONTRACT COMPLETION FOR SHOP-SETS
COMPARISON BETWEEN SHOP-SET CURVE AND AIRCRAFT AND DOD CURVES



## APPENDIX B - TABLE I

TABLE I - PERCENT OF TERMINATION LIABILITY FOR VARIOUS LEADTIMES (AVSCOM)

Lead Time in Months

| 6 | | 9 | | 12 | | 15 | |
|---|---|---|---|---|---|---|---|
| DOD | AVSCOM | DOD | AVSCOM | DOD | AVSCOM | DOD | AVSCOM |
| 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| 93.33 | 96.90 | 91.65 | 98.36 | 97.92 | 98.91 | 98.78 | 99.19 |
| 73.97 | 88.02 | 89.64 | 94.80 | 93.33 | 96.90 | 95.43 | 97.85 |
| 46.10 | 69.14 | 69.45 | 88.02 | 85.12 | 93.47 | 90.71 | 95.71 |
| 20.38 | 40.51 | 54.24 | 76.69 | 73.97 | 88.02 | 82.93 | 92.56 |
| 5.41 | 12.16 | 38.56 | 60.40 | 60.35 | 79.99 | 73.96 | 88.02 |
| 0 | 0.00 | 23.73 | 40.51 | 46.10 | 69.14 | 63.03 | 81.62 |
| | | 11.83 | 20.58 | 32.25 | 55.68 | 51.76 | 73.82 |
| | | 3.49 | 5.59 | 20.58 | 40.51 | 40.42 | 64.04 |
| | | 0 | 0.00 | 11.72 | 25.31 | 29.77 | 52.73 |
| | | | | 5.41 | 12.16 | 20.58 | 40.51 |
| | | | | 1.70 | 3.18 | 13.29 | 28.24 |
| | | | | 0 | 0.00 | 7.69 | 17.01 |
| | | | | | | 3.57 | 7.95 |
| | | | | | | 1.27 | 2.65 |
| | | | | | | 0 | 0.00 |

| 18 | | 21 | | 24 | | 27 | |
|---|---|---|---|---|---|---|---|
| DOD | AVSCOM | DOD | AVSCOM | DOD | AVSCOM | DOD | AVSCOM |
| 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| 99.04 | 99.35 | 98.12 | 99.46 | 99.60 | 99.54 | 99.36 | 99.60 |
| 96.77 | 98.37 | 96.25 | 98.69 | 97.92 | 98.91 | 98.29 | 99.07 |
| 93.33 | 96.90 | 94.38 | 97.60 | 95.87 | 98.05 | 96.77 | 98.37 |
| 88.52 | 94.81 | 89.07 | 96.09 | 93.33 | 96.90 | 94.48 | 97.43 |
| 81.38 | 91.90 | 83.76 | 94.07 | 89.81 | 95.40 | 91.72 | 96.28 |
| 73.96 | 88.02 | 78.45 | 91.41 | 85.12 | 93.47 | 88.52 | 94.81 |
| 64.91 | 82.98 | 73.97 | 88.02 | 79.76 | 91.03 | 83.76 | 92.97 |
| 55.51 | 76.70 | 64.48 | 83.77 | 73.96 | 88.02 | 78.00 | 90.73 |
| 46.10 | 69.14 | 55.00 | 78.62 | 67.23 | 84.35 | 73.97 | 88.02 |
| 36.68 | 60.40 | 46.34 | 72.53 | 60.35 | 79.99 | 67.93 | 84.79 |
| 28.12 | 50.75 | 38.67 | 65.53 | 53.15 | 74.93 | 61.77 | 81.05 |
| 20.58 | 40.51 | 31.06 | 57.74 | 46.09 | 69.14 | 55.51 | 76.70 |
| 14.38 | 30.26 | 25.79 | 49.31 | 39.00 | 62.69 | 49.24 | 71.79 |
| 9.38 | 20.58 | 20.58 | 40.51 | 32.20 | 55.68 | 42.96 | 66.56 |
| 5.41 | 12.16 | 13.05 | 31.70 | 26.14 | 48.22 | 36.63 | 60.04 |
| 2.64 | 5.59 | 10.37 | 23.25 | 20.58 | 40.51 | 30.97 | 54.05 |
| 1.01 | 1.43 | 7.69 | 15.58 | 15.77 | 32.80 | 25.60 | 47.38 |
| 0 | 0.00 | 5.44 | 9.08 | 11.73 | 25.31 | 20.58 | 40.51 |
| | | 3.19 | 4.14 | 8.30 | 18.33 | 16.45 | 33.65 |
| | | 0.94 | 1.05 | 5.41 | 12.16 | 12.72 | 26.94 |
| | | 0 | 0.00 | 3.21 | 7.03 | 9.38 | 20.58 |
| | | | | 1.70 | 3.18 | 6.73 | 14.79 |
| | | | | 0.74 | 0.81 | 4.48 | 9.72 |
| | | | | 0 | 0.00 | 2.64 | 5.59 |
| | | | | | | 1.52 | 2.53 |
| | | | | | | 0.74 | 0.64 |
| | | | | | | 0 | 0.00 |

Lead Time in Months

| DOD | AVSCOM | 33 DOD | 33 AVSCOM | 36 DOD | 36 AVSCOM | 39 DOD | 39 AVSCOM |
|---|---|---|---|---|---|---|---|
| 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| 99.72 | 99.65 | 99.17 | 99.68 | 99.83 | 99.71 | 98.88 | 99.74 |
| 98.27 | 99.19 | 98.33 | 99.28 | 99.14 | 99.35 | 97.75 | 99.41 |
| 97.08 | 98.66 | 97.50 | 98.77 | 97.92 | 98.91 | 96.62 | 99.02 |
| 95.43 | 97.85 | 95.68 | 98.14 | 96.77 | 98.37 | 95.38 | 98.54 |
| 93.33 | 96.90 | 93.85 | 97.36 | 95.21 | 97.70 | 94.13 | 97.97 |
| 90.71 | 95.73 | 92.02 | 96.40 | 93.33 | 96.90 | 92.88 | 97.29 |
| 87.35 | 94.30 | 88.74 | 95.25 | 91.33 | 95.95 | 90.92 | 96.48 |
| 82.93 | 92.56 | 85.47 | 93.86 | 88.52 | 94.81 | 88.97 | 95.53 |
| 78.57 | 90.48 | 82.20 | 92.21 | 85.12 | 93.47 | 87.02 | 94.42 |
| 73.97 | 88.02 | 78.09 | 90.27 | 81.53 | 91.90 | 83.86 | 93.13 |
| 68.61 | 85.14 | 73.97 | 88.02 | 77.90 | 90.09 | 80.71 | 91.64 |
| 63.03 | 81.82 | 68.61 | 85.42 | 73.97 | 88.02 | 77.56 | 89.94 |
| 57.62 | 78.06 | 63.72 | 82.46 | 69.45 | 85.65 | 73.97 | 88.02 |
| 51.76 | 73.82 | 58.83 | 79.13 | 64.91 | 82.98 | 70.51 | 85.84 |
| 46.10 | 69.14 | 53.94 | 75.42 | 60.35 | 79.99 | 67.15 | 83.41 |
| 40.43 | 64.04 | 48.50 | 71.33 | 55.65 | 76.70 | 63.03 | 80.71 |
| 34.85 | 58.54 | 43.07 | 66.86 | 50.85 | 73.08 | 58.89 | 77.74 |
| 29.72 | 52.74 | 37.64 | 62.07 | 46.10 | 69.14 | 54.75 | 74.51 |
| 24.98 | 46.70 | 33.28 | 56.98 | 41.37 | 64.91 | 50.47 | 70.99 |
| 20.58 | 40.51 | 28.93 | 51.65 | 36.69 | 60.40 | 46.02 | 67.23 |
| 16.69 | 34.33 | 24.58 | 46.13 | 32.25 | 55.68 | 41.94 | 63.21 |
| 13.29 | 28.26 | 20.58 | 40.51 | 28.13 | 50.75 | 37.64 | 58.98 |
| 10.28 | 22.44 | 16.94 | 34.88 | 24.22 | 45.67 | 33.85 | 54.56 |
| 7.69 | 17.03 | 13.29 | 29.34 | 20.58 | 40.51 | 29.77 | 49.97 |
| 5.41 | 12.16 | 10.05 | 23.99 | 17.29 | 35.37 | 25.18 | 45.28 |
| 3.57 | 7.95 | 8.80 | 18.94 | 14.38 | 30.26 | 20.58 | 40.51 |
| 2.22 | 4.56 | 6.55 | 14.29 | 11.72 | 25.30 | 16.17 | 35.75 |
| 1.22 | 2.05 | 4.94 | 10.15 | 9.38 | 20.58 | 13.85 | 31.05 |
| .60 | 0.32 | 3.32 | 6.62 | 7.27 | 16.17 | 11.55 | 26.43 |
| 0 | 0.00 | 1.70 | 3.78 | 5.39 | 12.16 | 9.21 | 22.01 |
| | | 1.15 | 1.70 | 3.52 | 8.60 | 7.61 | 17.82 |
| | | .57 | 0.43 | 2.63 | 5.59 | 6.01 | 13.96 |
| | | 0 | 0.00 | 1.70 | 3.18 | 4.40 | 10.45 |
| | | | | 1.05 | 1.43 | 3.43 | 7.38 |
| | | | | .51 | 0.36 | 2.46 | 4.79 |
| | | | | 0 | 0.00 | 1.49 | 2.72 |
| | | | | | | .94 | 1.22 |
| | | | | | | .45 | 0.31 |
| | | | | | | 0 | 0.00 |

Lead Time in Months

| 42 | | 45 | | 48 | | 51 | |
|---|---|---|---|---|---|---|---|
| DOD | AVSCOM | DOD | AVSCOM | DOD | AVSCOM | DOD | AVSCOM |
| 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| 99.08 | 99.76 | 99.43 | 99.78 | 99.82 | 99.79 | 99.78 | 99.80 |
| 98.12 | 99.46 | 98.85 | 99.51 | 99.60 | 99.54 | 99.56 | 99.57 |
| 97.18 | 99.11 | 98.27 | 99.19 | 98.76 | 99.25 | 99.34 | 99.31 |
| 96.25 | 98.69 | 97.33 | 98.81 | 97.92 | 98.91 | 98.31 | 99.00 |
| 95.31 | 98.19 | 96.38 | 98.37 | 96.90 | 98.51 | 97.28 | 98.64 |
| 94.38 | 97.60 | 95.43 | 97.85 | 95.87 | 98.05 | 96.25 | 98.29 |
| 93.33 | 96.90 | 93.85 | 97.24 | 94.60 | 97.52 | 94.99 | 97.74 |
| 89.07 | 96.09 | 92.28 | 96.54 | 93.33 | 96.90 | 93.73 | 97.20 |
| 86.42 | 95.15 | 90.71 | 95.73 | 91.57 | 96.20 | 92.47 | 96.58 |
| 83.76 | 94.07 | 88.13 | 94.81 | 89.81 | 95.40 | 90.76 | 95.88 |
| 81.10 | 92.83 | 85.53 | 93.76 | 87.47 | 94.49 | 89.04 | 95.09 |
| 78.45 | 91.41 | 82.93 | 92.56 | 85.12 | 93.47 | 87.32 | 94.20 |
| 76.21 | 89.81 | 79.95 | 91.21 | 82.44 | 92.32 | 84.67 | 93.21 |
| 73.97 | 88.02 | 76.96 | 89.70 | 79.76 | 91.03 | 82.01 | 92.10 |
| 69.23 | 86.01 | 73.97 | 88.02 | 76.86 | 89.60 | 79.35 | 90.87 |
| 64.48 | 83.77 | 70.32 | 86.14 | 73.97 | 88.02 | 76.66 | 89.51 |
| 59.74 | 81.31 | 66.68 | 84.08 | 70.60 | 86.26 | 73.97 | 88.02 |
| 55.00 | 78.62 | 63.03 | 81.82 | 67.23 | 84.35 | 70.89 | 86.38 |
| 52.04 | 75.69 | 59.28 | 79.36 | 63.79 | 82.27 | 67.59 | 84.59 |
| 49.07 | 72.53 | 55.52 | 76.70 | 60.35 | 79.99 | 64.38 | 82.64 |
| 46.10 | 69.14 | 51.76 | 73.82 | 56.75 | 77.55 | 61.19 | 80.54 |
| 41.06 | 65.53 | 47.99 | 70.75 | 53.15 | 74.93 | 57.99 | 78.29 |
| 36.03 | 61.73 | 44.21 | 67.49 | 49.63 | 72.11 | 54.87 | 75.87 |
| 31.00 | 57.74 | 40.43 | 64.04 | 46.10 | 69.14 | 51.75 | 73.29 |
| 28.49 | 53.59 | 36.68 | 60.40 | 42.55 | 66.00 | 48.25 | 70.56 |
| 25.79 | 49.31 | 33.23 | 56.64 | 39.00 | 62.69 | 44.76 | 67.68 |
| 23.18 | 44.93 | 29.77 | 52.74 | 35.63 | 59.25 | 41.27 | 64.66 |
| 20.58 | 40.51 | 26.71 | 48.73 | 32.25 | 55.68 | 37.98 | 61.50 |
| 16.82 | 36.09 | 23.64 | 44.65 | 35.30 | 51.99 | 34.69 | 58.21 |
| 13.05 | 31.70 | 20.58 | 40.51 | 26.14 | 48.22 | 31.40 | 54.82 |
| 11.71 | 27.41 | 17.15 | 36.39 | 23.36 | 44.39 | 28.50 | 51.34 |
| 10.37 | 23.25 | 16.72 | 32.29 | 20.58 | 40.51 | 25.60 | 47.76 |
| 9.03 | 19.29 | 13.29 | 28.36 | 18.17 | 36.64 | 22.70 | 44.13 |
| 7.69 | 15.58 | 11.34 | 24.33 | 15.77 | 32.80 | 20.58 | 40.51 |
| 6.57 | 12.16 | 9.38 | 20.58 | 13.75 | 29.00 | 18.34 | 36.87 |
| 5.44 | 9.08 | 7.69 | 17.03 | 11.72 | 25.30 | 16.09 | 33.24 |
| 4.32 | 6.39 | 6.32 | 13.71 | 10.01 | 21.74 | 14.16 | 29.67 |
| 3.19 | 4.14 | 4.94 | 10.68 | 8.30 | 18.33 | 12.22 | 26.27 |
| 2.07 | 2.35 | 3.57 | 7.95 | 6.86 | 15.13 | 10.28 | 22.77 |
| 0.94 | 1.05 | 2.64 | 5.59 | 5.41 | 12.16 | 8.77 | 19.52 |
| 0.44 | 0.25 | 1.96 | 3.62 | 4.31 | 9.44 | 7.26 | 16.42 |
| 0 | 0.00 | 1.27 | 2.05 | 3.21 | 7.03 | 5.75 | 13.53 |
| | | 0.53 | 0.91 | 2.45 | 4.94 | 4.80 | 10.85 |
| | | 0.41 | 0.23 | 1.70 | 3.18 | 3.85 | 8.42 |
| | | 0 | 0.00 | 1.22 | 1.80 | 2.90 | 6.25 |
| | | | | 0.74 | 0.81 | 2.30 | 4.38 |
| | | | | 0.38 | 0.20 | 1.71 | 2.82 |
| | | | | 0 | 0.00 | 1.11 | 1.60 |
| | | | | | | 0.72 | 0.71 |
| | | | | | | 0.36 | 0.18 |
| | | | | | | 0 | 0.00 |

Lead Time in Months

| DOD | AVSCOM | 57 DOD | 57 AVSCOM | 60 DOD | 60 AVSCOM |
|---|---|---|---|---|---|
| 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 99.82 | 99.63 | 99.83 | 99.86 | 99.83 |
| 99.36 | 99.60 | 99.26 | 99.63 | 99.72 | 99.65 |
| 99.04 | 99.35 | 98.89 | 99.40 | 98.99 | 99.43 |
| 98.29 | 99.07 | 98.19 | 99.13 | 98.27 | 99.19 |
| * | 98.74 | 97.49 | 98.83 | 97.92 | 98.91 |
| 96.77 | 98.37 | 96.79 | 98.49 | 97.08 | 98.60 |
| * | 98.06 | 95.80 | 98.10 | 96.26 | 98.24 |
| 94.48 | 97.45 | 94.81 | 97.66 | 95.43 | 97.85 |
| 93.33 | 96.90 | 93.82 | 97.17 | 94.38 | 97.40 |
| 91.72 | 96.28 | 92.42 | 96.62 | 93.33 | 96.90 |
| * | 95.59 | 91.01 | 96.00 | 92.02 | 96.35 |
| 88.52 | 94.81 | 89.61 | 95.31 | 90.71 | 95.73 |
| * | 93.94 | 88.31 | 94.54 | 89.03 | 95.05 |
| 83.76 | 92.97 | 89.01 | 93.69 | 87.35 | 94.30 |
| 81.38 | 91.90 | 85.71 | 92.75 | 85.12 | 93.47 |
| 78.90 | 90.73 | 82.55 | 91.73 | 82.93 | 92.56 |
| * | 89.43 | 79.40 | 90.60 | 80.75 | 91.56 |
| 73.97 | 88.02 | 76.25 | 89.36 | 78.57 | 90.48 |
| * | 86.46 | 73.97 | 88.02 | 76.27 | 89.29 |
| 67.93 | 84.79 | 69.86 | 86.55 | 73.97 | 88.02 |
| 64.91 | 82.98 | 65.75 | 84.98 | 71.29 | 86.63 |
| 61.77 | 81.03 | 63.93 | 83.27 | 68.61 | 85.14 |
| * | 78.93 | 62.12 | 81.45 | 65.82 | 83.54 |
| 55.51 | 76.70 | 60.31 | 79.49 | 63.03 | 81.82 |
| * | 74.31 | 56.99 | 77.42 | 60.35 | 79.99 |
| 49.24 | 71.79 | 53.67 | 75.21 | 57.62 | 78.06 |
| 46.10 | 69.14 | 50.35 | 72.87 | 54.69 | 76.00 |
| 42.96 | 66.36 | 48.18 | 70.42 | 51.76 | 73.82 |
| * | 63.45 | 46.00 | 67.83 | 48.93 | 71.54 |
| 36.68 | 60.40 | 42.88 | 65.14 | 46.10 | 69.14 |
| * | 57.27 | 39.78 | 62.33 | 43.27 | 66.63 |
| 30.97 | 54.05 | 36.67 | 59.43 | 40.43 | 64.04 |
| 28.12 | 50.75 | 33.55 | 56.44 | 37.64 | 61.33 |
| 25.60 | 47.38 | 30.69 | 53.36 | 34.85 | 58.74 |
| * | 43.97 | 27.82 | 50.22 | 32.25 | 55.68 |
| 20.58 | 40.51 | 24.95 | 47.01 | 29.77 | 52.74 |
| * | 47.07 | 22.77 | 43.78 | 27.38 | 49.73 |
| 16.45 | 33.65 | 20.58 | 40.51 | 24.98 | 46.70 |
| 14.38 | 30.26 | 18.65 | 37.26 | 22.70 | 43.62 |
| 12.72 | 26.94 | 16.87 | 34.00 | 20.58 | 40.51 |
| * | 23.70 | 15.08 | 30.79 | 18.64 | 37.42 |
| 9.38 | 20.58 | 13.29 | 27.64 | 16.69 | 34.33 |
| * | 17.60 | 11.70 | 24.54 | 14.90 | 31.26 |
| 6.73 | 14.79 | 10.11 | 21.56 | 13.29 | 28.26 |
| 5.41 | 12.16 | 8.51 | 18.68 | 11.72 | 25.30 |
| 4.48 | 9.72 | 7.65 | 15.95 | 10.28 | 24.14 |
| * | 7.53 | 6.78 | 13.39 | 8.40 | 19.68 |
| 2.64 | 5.59 | 5.91 | 10.98 | 7.69 | 17.03 |
| * | 3.92 | 5.02 | 8.78 | 6.55 | 14.51 |
| 1.52 | 2.53 | 4.14 | 6.79 | 5.41 | 12.16 |
| 1.43 | 1.43 | 3.25 | 5.04 | 4.49 | 9.96 |
| 0.74 | 0.64 | 2.84 | 3.52 | 3.57 | 7.95 |
| * | 0.16 | 2.03 | 2.27 | 2.90 | 6.15 |
| 0 | 0.00 | 1.42 | 1.28 | 2.22 | 4.56 |
| | | 0.79 | 0.57 | 1.70 | 3.18 |
| | | 0.35 | 0.14 | 1.27 | 2.05 |
| | | 0 | 0.00 | 0.94 | 1.16 |
| | | | | 0.60 | 0.52 |
| | | | | 0.31 | 0.13 |
| | | | | 0 | 0.00 |

# APPENDIX C -

# DERIVATION OF EQUATION FOR "EQUALLY LIKELY" CURVE

## APPENDIX C-

## DERIVATION OF EQUATION FOR AVERAGE OR "EQUALLY LIKELY" CURVE

Upon close inspection of the average or "equally likely" curve shown in Figure 10, it was noted that the shape of the curve is the same as the shape of the curve described by the function.

$$Y = A\left[1-e^{-BX^2}\right] \tag{1}$$

Now, in the above expression, the independent variable is "X" and the dependent variable "Y." For the average curve, the independent variable is percent contract completion and the dependent variable percent contract cost. Consequently, we shall allow

X - percent contract completion

Y - percent contract cost

Since percent contract completion and percent contract cost must be positive, the following discussion will only consider positive values of "X" and "Y." From Figure 10 it will be seen that two of the points through which the average curve goes are the (0,0) and the (100,100) points. The first point indicates that no contract costs are incurred at the time the contract begins. The second point indicates that all of the contract costs must have been incurred when a contract has been completed. Substituting

$$X = 0$$

into equation (1) we find that

$$Y = 0$$

also. Thus, the whole family of curves described by equation (1) goes through the (0,0) point, and it is not necessary to choose any certain values of the constants, "A" and "B" in order to fit the equation through the (0,0) point. Since it was not necessary to solve for either constant in order to make the equation go through the (0,0) point, there are still two undetermined constants and equation (1) may be fit through two additional points on the graphically constructed average curve. Thus, equation (1) will pass through a total of three of the points on the graphical curve.

For the two additional points, we choose "X" values of 50 and 100 percent; the corresponding "Y" values are 60.3 and 100 percent, respectively.

The next step is solving equation (1) for "B." Dividing both sides by "A" yields

$$\frac{Y}{A} = 1-e^{-BX^2} \tag{2}$$

Adding negative one to both sides of equation (2) gives

$$\frac{Y}{A} - 1 = -e^{-BX^2} \tag{3}$$

If equation (3) is multiplied by negative one, the result is

$$1 - \frac{Y}{A} = e^{-BX^2} \tag{4}$$

If the natural logarithm of both sides of equation (4) is taken,

$$Ln\left[1 - \frac{Y}{A}\right] = -BX^2 \tag{5}$$

is obtained.

Substituting the point values (50.0, 69.5) and (100.0, 100.0) into equation (5) gives the two equations

$$LN\left[1 - \frac{60.3}{A}\right] = -B\,(50.0)^2$$

and (6-a)

$$LN\left[1 - \frac{100.0}{A}\right] = -B\,(100.0)^2$$

or

$$LN\left[1 - \frac{60.3}{A}\right] = -2{,}500B \qquad (6\text{-}b)$$

and

$$LN\left[1 - \frac{100.0}{A}\right] = -10{,}000B$$

Solving the two equations for "B," and then setting them equal, yields

$$LN\left[1 - \frac{100.0}{A}\right] = 4LN\left[1 - \frac{60.3}{A}\right] \qquad (7)$$

Eq. (7) cannot be solved by standard algebraic techniques, so it is necessary to employ an iterative technique. Solving equation (7) iteratively gives

$$A = 103.0597$$

The corresponding value of "B" is obtained by substituting the above value of "A" into either of equations (6-b). This yields

$$B = 3.5170 \times 10^{-4}$$

In order to make equation (1) more convenient for use, we round off the value of "A" so that

$$A = 103$$

This gives a corresponding value of

$$B = 3.5362 \times 10^{-4}$$

Substituting the "A" and "B" values into equation (1) gives a result of

$$Y = 103\left[1-e^{-0.00035362X^2}\right] \qquad (8)$$

A comparison between the average curve and the plot of equation (8) is shown in Figure 11. It will be seen that the plot of equation (8) provides an excellent approximation to the average curve.

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